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HEMISPHERE SEARCH DETECTOR

Progress Report No. 6

(Period October 2, 1948, to November 1, 1948)

Under

U.S. Navy Contract No. NObsr-42179

November 1, 1948

Polaroid Corporation

Research Department

Cambridge 39, Massachusetts

(Project RC-5)

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A good start has now been made on the electronic circuits to be incorporated in the hemisphere search detector whose design is the primary aim of this study contract. This electronic work is being carried out by Dr. Stockman.

A meeting was held in Washington on October 13, attended by Mr. Dauber of the Navy and Harry Stockman of Polaroid. The minutes of this meeting are attached as enclosure 1.

Three reports by Dr. Stockman dated September 27, September 30, and October 3 are attached as enclosures 2, 3, and 4.

Enclosure 2 is an overall survey of the electronic system. This overall survey states the framework within which the further discussion of the electronic system will be carried out.

Enclosure 3 contains the information which has been accumulated to date on the switching tubes available, the detailed characteristics of two switching tubes manufactured by the Federal Telecommunication Laboratory and two tubes manufactured by the National Union Radio Corporation.

Enclosure 4 contains the result of the study of magnetic amplifiers. Considerable attention has been paid to magnetic amplifiers because it is hoped that they may be an answer to the old problem of coupling a low impedance device to the grid of the tube at low frequencies. This coupling may in principle be accomplished by transformers, but transformers with the very high secondary inductance required to yield an impedance of one megohm at one cycle per second are extremely heavy and bulky. It is hoped that magnetic amplifiers may permit the use of a much smaller magnetic structure because the magnetic amplifier may be used as a frequency converter. If a magnetic amplifier may be used in such a way that it does not degrade the signal-to-noise ratio of the detector itself, it appears to offer high promise because the secondary inductance need only be high enough to yield an impedance of one megohm at, say, 5000 cycles.

Work is now in progress to assemble the information required for the second report of the series of which the writer's September 24 report is the first member. This information is the amount of water vapor in the optical path as a function of the meteorological conditions, the elevation angle of the source, and the distance of the source.

This study contract was discussed with Dr. G. B. B. M. Sutherland when he visited the Polaroid Corporation on October 6. The minutes of this meeting are attached as enclosure 5. A specific design was worked out for the array of lead sulfide cells to be used in the 18 element scanner. If it is not convenient to manufacture this array in this country, Dr. Sutherland felt quite sure that it could be constructed in England.

rcj/cbb

Report prepared by R Clark Jones
R. Clark Jones

Approved by Elkan R. Blout
Elkan R. Blout
Associate Director of Research

Enclosure C

Minutes of a Meeting in Washington on Wednesday, October 13, 1948

Contract NObsr-42179

October 13, 1948

Harry Stockman

The meeting was held in the offices of the Bureau of Ships at the Navy Department Building on Constitution Avenue on Wednesday, October 13. Present were Mr. Harry Dauber, Navy, and Dr. Harry Stockman, Polaroid Corporation. The conference continued through the day. The discussion extended over a wide field. Only a few discussion points of particular interest are recorded in the following.

1. Planned future activities

Since the last Polaroid Corporation visit on September 3, 1948, Mr. Dauber had had several conferences with experts in the fields of magnetic recording, magnetic amplification, switching tubes, etc. It is the writer's understanding that Mr. Dauber plans in due time to initiate meetings between the Polaroid research workers and representatives of various firms, supposedly Armour Research Foundation (magnetic recording), NRL (magnetic amplifiers), and National Union (switching tubes). Such a meeting will probably extend over a period of two days, and would certainly be very much worth while. Mr. Dauber pointed out that initial results may be available next month from Armour and NRL.

2. Visual presentation

The final form of the presentation unit has a definite bearing on the preceding circuits of the hemispheric search detector, and it is logical to give preference in this discussion to the final link in the search detector system.

If the time constant of the PPI tube is made long, the contrast will fall off with time, and the response from one 15-second sweep can therefore not be held over to the following sweep simply by means of a long persistence screen. For this reason Mr. Dauber has suggested that the screen be given a rather short time constant, one-half or one second, or so, and that the persistence be provided artificially, for example, by means of storage in magnetic recorders. For this reason the Armour Research Foundation has become involved in the presentation problem, and we are expected in the immediate future to present our problem to the Armour experts in a precise and concise form. The writer mentioned that "memory" tubes, with a dielectric screen operating more or less as an equivalent to the phonograph record, have been under consideration by manufacturers associated with USAF (example: Raytheon Manufacturing Company). It may be of interest to investigate this matter further.

It must be realized that whatever artificial persistence scheme is employed, it must operate right from the noise level, which means that "memories" of noise will be redistributed all the time over the entire PPI screen. In order to prevent signal-to-noise degradation from this effect, and partly to establish a "one in all" presentation, Mr. Dauber suggested a scheme illustrated in Fig. 1. Here the functions of four PPI tubes are combined in one, each CRC screen having the form of a circular segment, radially divided into 18 intervals for the available 18 channels.

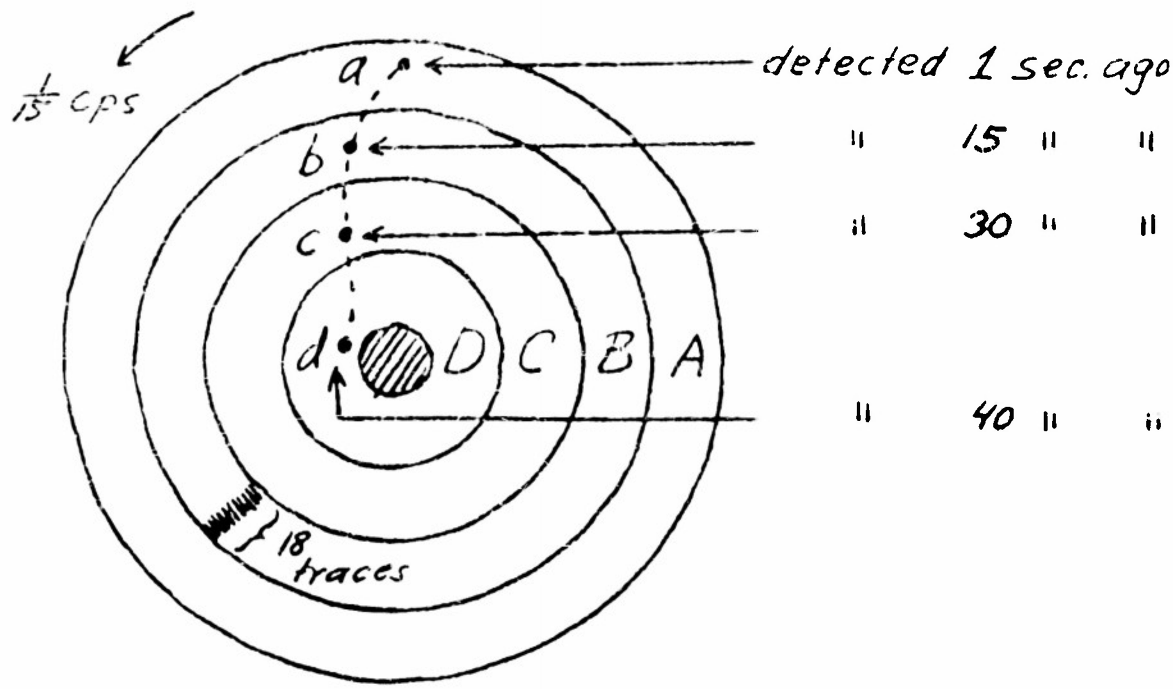

Fig. 1

The ring segments A, B, C, D are identical except that they are of different size. Ring A is the up-to-date one, which shows what is happening "just now," during the very latest 15-second sweep. Ring B shows what the "condition" was during previous sweep. Ring C shows what the "condition" was during the preceding sweep, etc. When the "memory trace" abcd becomes four 15-second sweeps long, the oldest "memory" is wiped out, and the ring D fed from the record that previously fed ring C, and so on. In this way a continuous record of the "past history" of the target is maintained, although it may require some training to properly visualize the true concept of the trace abcd.

The storage can be accomplished by magnetic means similar to those now under consideration by the Armour Research Foundation for another purpose. It is realized that this method involves circuitry considerably more complicated than the single dimension unit to be developed by Armour for SSD operation. It is felt at this time that the presentation system for the hemispheric search detector will be an evolution from this particular device.

Mr. Dauber also mentioned other forms of presentation, the original schemes with one CRO screen, showing all past target history in well known PPI fashion, and other schemes, such as elevation vs. azimuth coordinate systems.

3. <u>The Nancy-Sue Report</u>

A related project to the hemispheric search detector is "Nancy-Sue," partly described in Interim Report of August, 1946 - December, 1947, by RCA, Camden, New Jersey, Contract NObsr-30143. "Nancy-Sue" utilizes an infrared device for detection, and then flashes on during an extremely short time interval a narrow beam radar for range determination. The infrared detector utilizes two cells in a bucking scheme, which arrangement gives certain advantages, for example, with respect to desirable signal waveform and noise background.

4. <u>Magnetic amplifiers</u>

Mr. Dauber mentioned that NRL is investigating the application of magnetic amplifiers to infrared work and other problems. The head of this investigation at NRL is Mr. H. I. Clark, Engineering Section, Optics Division.

It is believed that a possibility exists that the magnetic amplifier, in a future specialized and improved form, provides the answer to the problem of amplifying the thermocouple output.

5. <u>Automatic sun protection</u>

Mr. Dauber stated that it would be sufficient here to indicate the principle of the circuits rather than to provide detailed information, particularly as the first model to be built would be operated essentially during the night. This statement also applied to protection against certain overload conditions. Certain phases of the research work on such refinements as automatic sun protection should, however, be given very general consideration, as the choice of principle and methods for the essential parts of the electronic circuits to a large extent determines the applicability of later refinements.

6. <u>Switching tube circuits</u>

It now appears rather definite that National Union will be able to deliver a switching tube that fits our needs very well. While the number of electrodes, 12 in conventional tubes, would only permit an experimental system of restricted resolution characteristics, a "multi-electrode" type will be available in the future with 30 electrodes. This suggests the possibility of the group of 12 electrodes for transmission of the synchronization signal. It is also possible that National Union would make a test sample with 19 electrodes, one for synchronization and 18 for the channels.

Important information regarding signal voltage requirements of the switching tube was given by Mr. Deuber. Tubes have been made by National Union in which a signal in the range of 10-50 microvolts is detectable above noise.* Magnetically focussed tubes are preferable, as most applications of the electrostatically focussed tubes are at higher signal levels. The disturbances in the radial beam tubes referred to arise from two chief sources. The first is the ordinary random noises from shot effect, flicker effect, and random division of current. The second type of disturbance is generated by the rotation of the beam. In general it increases with the rotation rate of the beam and is strongest at a frequency equal to the product of the rotational rate by the number of channels scanned per second. It is therefore advantageous to operate with low rotational deflection frequency. The absence of scanning noise depends on having very smooth commutation; again smooth commutation may cause difficulties with respect to permissible amount of crosstalk between channels.

With reference to future high resolution types of search detectors with an increased number of cells, it is of interest to know that National Union considers a number of 50 electrodes, or so, as the maximum to be put into a switching tube at the time being. Mr. Deuber briefly reviewed the other proposed solution, the "lobe contour" method of obtaining high resolution, described by the writer at the September 3 meeting in Washington.

Viewpoints on General Design

With reference to Mr. Deuber's information on the high useful sensitivity of the switching tube, it appears that a design might be possible, where the switching tube is arranged early in the system with only a small amount of amplification prior to each electrode. It was temporarily assumed that a signal of a volt or a tenth of a volt would require approximately 100 db preamplification. A reduction in input signal of the order indicated would cut the db figure to approximately half. In reality, however, various factors must be taken into account which increase requirements on the amount of preamplification needed.

The question was discussed of the suitable value for the circular deflection frequency of the switching tube, which is the same as the radial deflection frequency of the PPI. Valuable comments were made,

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* See also letter of October 11, 1948, from National Union to Polaroid Corporation.

but the time did not permit a final discussion of the subject matter. It appears that a value of 200 cps or so provides a good starting out point for design considerations.

Mr. Dauber brought up the question of cooling, which is closely associated with the problem of type of cell to be used, type of amplification, etc. He stated that selenide cells now are within reach, which will be improved so that cooling may not be a necessary consideration in future design. This is important, said Mr. Dauber, as it is impractical to use any conventional cooling system on top of the mast, and it would be almost necessary to find ways and means for designing uncooled systems. (Cooling has, of course, only been considered for the "hot" channel, utilizing lead selenide or lead sulfide cells.) Mr. Dauber suggested the Photo-mo Company as a supplier of lead sulfide cells for experimental urposes.

The mechanical system as it now seems to shape up would therefore have per channel one cell amplifier immediately adjacent to the cell, one preamplifier mounted outside the "sector-box" containing the mirror and the arc of cells, synchronous commutators, and, common to all channels, the switching tube with associated circuits and devices. All this would rotate, and be connected via slip-rings to the output signal lead and line amplifier, and to the various supplies needed (probably a 400 cps power line).

Mr. Dauber suggested that it would be sufficient to provide the openings in the scanner with silver chloride windows. No dome arrangement is needed. The two spherical mirrors should be arranged inside proper housing so that the positions and viewing angles could be varied by means of adjustment screws. It was agreed that the "hot" (photocell) channel and the "warm" (thermopile) channel can be made complete in themselves, so that simultaneous operation on the same target becomes possible for direct comparison.

hs/cbb

Overall Electronic System for the Hemispheric Search Detector, Model 1

September 27, 1948

Harry Stockman

The solution shown in Fig. 1 was proposed by the writer immediately before the discussion meeting in Washington, September 3, 1948, and Fig. 1, a slightly modified version of the block diagram presented during this meeting, merely serves to illustrate the basic principle. The optical scanner is shown in symbolic form in the left upper corner, and the presentation PPI tube in the lower left corner. The physical distance between these two units is that between the top of the mast and the control or display room inside the ship.

Part of this proposal is to use a time sequence switching tube up in the mast, which yields the two advantages of a single line connection and time sequence presentation on the PPI display tube. The time division (multiplex signalling) switching tube is inserted between the optical scanner and the line or down lead. For the time being it is assumed that a tube with 18 input electrodes is available. The switching period T_B is then divided into 18 intervals, each one of duration $T_B/18$ representing a channel. Each time the circuit is completed through electrode 1; cell 1 in the optical scanner is connected during an interval of time somewhat less than $T_B/18$ to the PPI tube, and an indication will be given on the proper place of the screen. The exposure time of a target (approximately 80 milliseconds) is large compared to $T_B/18$, so cell 1 will be connected to the PPI tube maybe 10 times, or so, before the radiation response from the target in cell 1 dies down. The same operation applies to cell 2, 3,...18. The switching tube is shown symbolically in form of a cathode-ray tube, in which the electron beam hits 18 electrodes in sequence, the intensity of the beam current varying in such a way as to follow the potentials on the 18 electrodes.

The principle also involves that rectifiers or synchronous commutators of proper time constants may be inserted between the chain of amplifiers, following the cells, and the input electrodes of the switching tube. This means that whatever chopping component, or carrier, that is introduced for other purposes in the cells or the preamplifiers, is eliminated by means of filtering before the signals are applied to the switching tube. The only variational component that reaches the switching tube is therefore the signal component from the target. The switching tube and presentation PPI tube circuits are therefore in this first approach independent of the type of cell used and of possible chopping or carrier insertion required for low noise operation. This adds flexibility to the system. It furthermore makes it easy to obtain the narrow bandwidths required by S/N consideration, whereas other approaches make it difficult to obtain the required narrow bandwidth.

It is estimated that the total amplification from one of the cells to the electrodes of the PPI tube is of the order of 150 db. It is evident that some of this amplification must be applied immediately following the cell to provide low-noise operation and sufficient input voltage to operate the switching tube. Another part of the amplification should be applied as line amplification between the switching tube output and the down lead, so that the signal will safely override the noise and interference in the line. The third part of the amplification should be applied as display amplification between the bottom end of the line and the presentation PPI tube. It is estimated with reference to the many unknown factors in Fig. 1 that the total amplification in a first approach may be split into three equal parts, or 50 db per amplification unit. The extremely small output from the cells, and the likely lack of sensitivity of the switching tube probably would favor a split such as 100 + 25 + 25. Assuming the same impedance (a few hundred ohms) through the entire system, this would yield the following voltage levels starting, as an example, with 0.1 microvolts; approximately 10 millivolts on the switching tube input electrodes, approximately 0.15 volts on the down lead input, and approximately 2.3 volts on the PPI tube input. These figures may be off by factors of 100, or so, but illustrate the principle behind the design.

In Fig. 1 the assumed amplification of 100 db between the cells and the switching tube has been further divided into three parts or units for circuit convenience. The first unit, the cell amplifier, is built right into the cell arc and mounted as close as possible to the individual cells. The second unit, or preamplifier, is mounted just outside the optical scanner, but also rotates with it. The third unit is stationary and fed via a slip ring arrangement. As a first approximation the division of gain in the three initial units may be estimated as 30 + 30 + 40 db, totalling 100 db.

If weight considerations permit, it will be desirable also to place the third unit and the switching tube on the rotating platform.

The arrangement of the PPI tube and its synchronization in Fig. 1 is as follows: A saw-tooth voltage of frequency $1/T_B$ is generated in a saw-tooth generator, located close to the PPI tube. The saw-tooth voltage is used to provide the deflection of the electron beam in the switching tube, and also to provide the radial sweep in the PPI tube, thus providing full synchronization. The cells in the optical scanner are here marked 1 to 18 from the zenith and down (the old terminology reversed), and the display units on the screen of the PPI tube marked 1 to 18 from the center and out. The dots on the radius indicate "no-signal" response from each cell, and the larger dot the response from a target on, say, channel 1[illegible], i.e., approximately on the elevation angle $12\frac{1}{2}^{\circ}$. The screen may be provided with a ring pattern or a transparent cover so that the elevation angle can be read directly. It is assumed that proper anti-zigzag circuits can be developed so that the zigzag arrangement of the cells does not prevent proper presentation of the targets on the display tube.

The radius sweeps around the PPI screen in synchronism with the rotational movement of the optical scanner. This may be accomplished by means of selsyn motors, fed from the ship's 400 cps power system. The frequency of this rotational movement is referred to as f_A and $f_A = 1/15$ cps.

It is of interest to estimate generally the approximate value of the circular deflection frequency f_B of the switching tube, which frequency is identical with the radial deflection frequency of the PPI tube. Tentatively the signal frequency has been previously assumed to cover the band 3 to 10 cps, with the center frequency at approximately 6 cps. Various arguments for increasing or decreasing the given frequency value can be given. Consider first a system with optical chopper of frequency $f_C = 500$ cps, say, and no rectification or synchronous commutation. It then appears desirable to scan each electrode in the switching tube several thousand times per second, so that many samples from each chopping pulse are obtained. The scanning frequency may then be as high as $f_B = 5000$ cps, and presently switching tubes seem to operate up to 10,000 cps. Consider next a system where rectification or synchronous commutation is employed. The signal pulses are here restored practically to their initial form before being applied to the electrodes of the switching tube. A rather low value of f_B is then sufficient. The minimum value is set by the PPI tube, for the radial traces must be repeated fast enough to appear as closely spaced straight lines, and the frequency must be high enough not to cause flicker effect. It appears that the minimum value is of the order of 100 cps, and a practical system may utilise 100 or 200 cps, unless special requirements from other parts of the system necessitate a higher value. In Fig. 1 the value $f_B = 100$ is satisfactory for the presentation circuits shown, but is not generally applicable to all the various kinds of input circuits, including optical scanning systems, that must be considered before a final design principle can be arrived at.

The given discussion is probably sufficient to give an idea of the basic principle considered. The writer is well aware of the fact that a number of difficulties and complications have been avoided or ignored in this text, such as overloading, dynamic range, time constants, recovery time, automatic sun protection, artificial screen persistence, multiple target response, cooling problem, etc. These matters will be discussed in later reports.

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Suggested Circuit, 1 Sept. 1948.

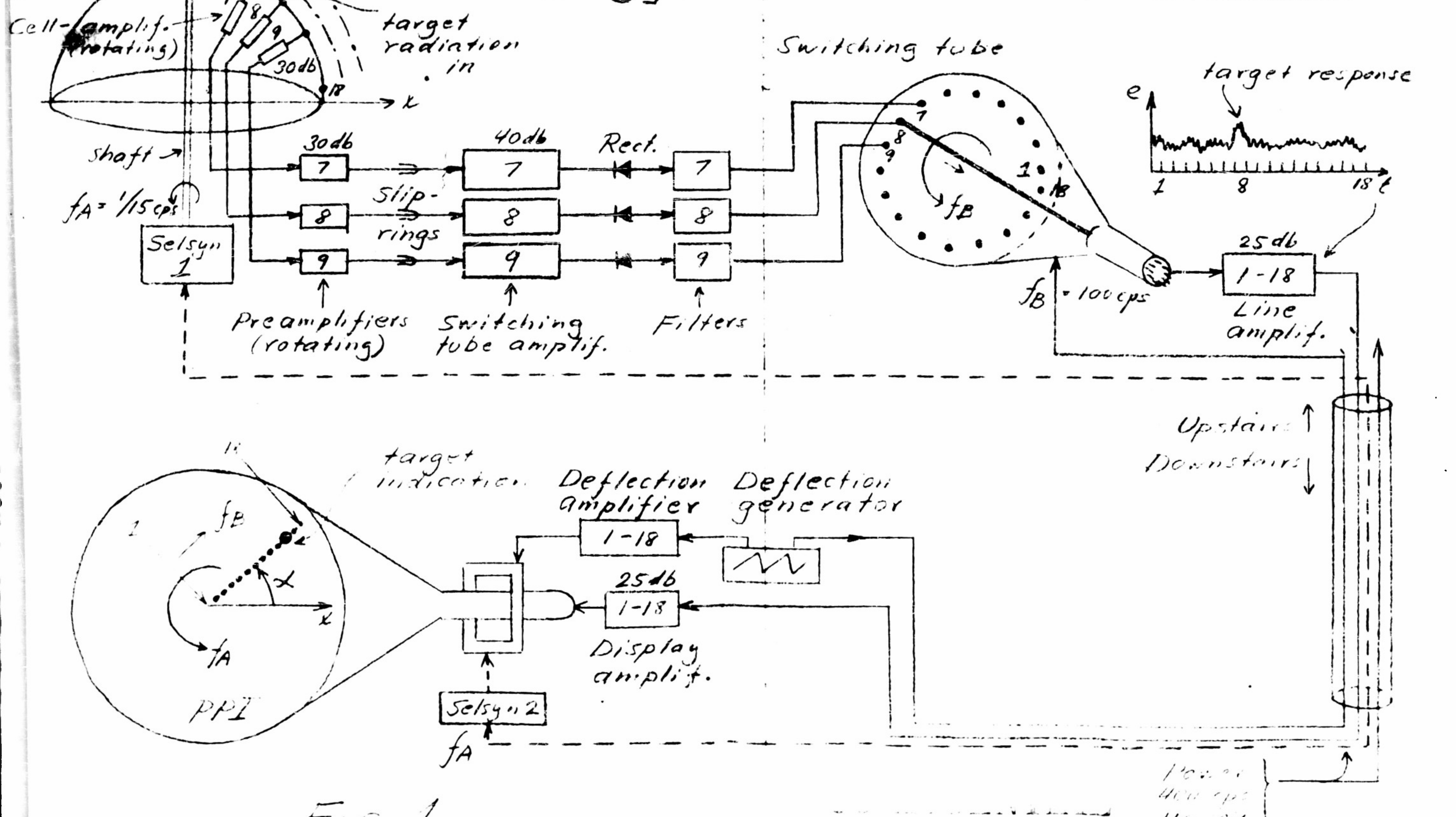

Fig 1.

1 Sept. 1948. H.S.

Switching Tubes for the
Hemispheric Search Detector, Model 1

September 30, 1948

Harry Stockman

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1. General. There are probably half a dozen or so switching tube manufacturers in the USA, but the writer has so far been able to contact only two of them. In the following some rather sketchy information is given on these tubes, but reasonably complete information will be available later, when answers have been obtained to questions recently issued to Federal Telecommunication Laboratory, and National Union Radio Corporation. At present very little is known about switching transients, but this matter will be given full consideration at a later time

2. The Federal "Cyclophons" X 153C and X 153G

This tube is built on the idea of spinning the beam in a cathode-ray tube so that the display point describes a circle. The ordinary screen is replaced by a circular set of 25 electrodes, called dynodes, or collectors, or secondary emitters. The signal electrode has the form of a disc with holes in front of each dynode. Figure 1 shows a circuit diagram of the Cyclophon tube.

The current output of each channel may be increased several times by the use of secondary emission from the dynodes (the aperture plate then has higher positive potential than the dynodes).

Crosstalk is obtained because adjacent circuits affect each other by either electric or magnetic induction. One difficulty at high frequency is the inter-dynode capacitances, but at 1000 cps the crosstalk in an adjacent channel is down approximately 60 db. Good design characteristics aimed at are low crosstalk, maximum output, uniformity and long life.

Type X 153C utilizes electric deflection, type X 153G magnetic deflection. The following data are of interest:

	X 153C	X 153G	
Accelerating anode volts	2000	2000	1000
Aperture anode volts	2000	2000	1000
Dynode volts	500	500	500
Deflection factor	135-170 volts/inch	70 gauss/inch	50 gauss/inch
Dynode currents (in mA)	1	30	12
Dynode load resistance	50,000	1000	5000

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The noise contribution is made up of shot effect, secondary-emission noise, and thermal agitation noise. The total noise power is approximately the same as that of a pentode amplifier.

It follows from the above that the Cyclophon is essentially an "output" tube in signaling multiplex circuits, and thus not directly adapted to our own needs. It is stated, however, that the tube also can be used as an "input" tube, and probably this is done by using the dynodes as input electrodes, and taking the output from the "signal in" contact in Fig. 1. Correspondence for clarification on this point has been entered into.

3. The National Union Radio Corporation Radial Beam Tubes RBM10G-1 and RBE12G-1

These tubes have at the most 12 electrodes, but it is possible that tubes with more electrodes will be available at a later time (correspondence initiated). The tubes are of coaxial type with a cylindrical shield, which has 12 windows. Behind each window a pair of paraxial wires serves as a control grid for the current to the anode, placed behind the grid wires. There is an inner grid closely surrounding the cathode. The electron beam has the form of a sheet of electrons, whirled around either by means of an electric or a magnetic field. Different "input" and "output" tubes are used in a time division multiplex circuit. The input tube has the grid leads brought out individually, and this tube is the one of interest to us. A simplified circuit diagram is shown in Fig. 2, representing tubes RBM10G-1 magnetically focussed. It has only 10 electrodes.

The various resistors R_1, R_2, R_3, and R_4 provide part of a two-phase voltage supply system used in connection with focussing and circular deflection or suppression of the undesired beam. The beam is always prevented from passing to the anode by a large negative voltage on the proper control grid.

The magnetic field is most easily obtained by using the stator of a small polyphase two-pole synchronous motor. In the gap of such a stator there are only two poles to the field so that the lines of force are parallel to the diameter. Other circuits for the production of the rotating magnetic field are given by the manufacturer. Of special interest are circuits for obtaining multiphase from single phase using tuned reactances or RC phase splitters. In connection with frequency multiplication or frequency division circuits, the 60 or 400 cps supply could be used (in the mast only 400) yielding a 200 or 100 cps two-phase output. Vacuum tube oscillators, using N tubes in a ring, will give N or 2N phase output, and may also be of interest.

The following characteristics are of interest for RBM10G-1:

Inner grid voltage	- 15 volts
Screen voltage	+ 90 volts
Anode voltage	+125 volts
Suppression grid voltage	Four phases a.c. voltage ~ 90 V peak per phase
Suppression grid bias voltage	-20 volts
Beam current	5 mA

Obviously a suppressor grid is inserted, although not mentioned by the manufacturer in the supplied text.

The electrostatically focussed (and circularly deflected) tubes are made much the same way as the magnetically focussed ones. The electrostatic field is established by applying suitable voltages to a number of screen segments, surrounding a central cathode. For instance, in a tube with six screen segments, a six-phase voltage applied to the segments results in a rotating electrostatic field much in the manner of the rotating magnetic field in the stator of a six-pole electric motor. A six segment tube handles twelve grid-plate systems, half of them via slits in the segments, the other half via the openings between segments.

Of special interest is a graph given by the manufacturer, showing the anode current in mA versus the signal control voltage in volts (referred to cathode). Three characteristics are given, the one for minimum supply voltage (type I in table below) almost straight and extending from 0 to -17 volts, and 0 to 0.4 mA (peak value). An equivalent, amplifying triode, would have a transconductance of roughly 0.4/17 ≙ 0.02 mA/V, which would be very low, and supposedly operate with a maximum peak voltage of 8 volts, and a minimum peak voltage of 0.1 volts, or so. This switching tube may therefore require an input of the order of volts, and may not operate at all on inputs of the order of millivolts. (Information on this point has been requested from the manufacturer.) Typical operating conditions are:

	I	II	III
Screen Voltage (rms, 6ϕ)	150 V	250 V	283 V
Cathode Voltage	80 V	138 V	152 V
Anode Supply Voltage	300 V	400 V	450 V
Peak Anode Current	0.35 mA	0.7 mA	0.8 mA

4. Conclusions

No conclusions should actually be drawn at this time due to the very meager information presently available on switching tubes. Again, certain facts are known, such as the number of electrodes, in the "Federal" tube 25, and in the "Union" tube, 12. "Federal" may not be suitable as "input" tube, while "Union" makes such tubes. It appears that all d.c. electrode voltages can be obtained from rectification of 400 cps on top of the mast. The focussing and circular deflection voltage can probably also be obtained from 400 cps via divider and single-to-multiphase circuits, but other alternatives are open, such as the use of tube oscillators with proper frequency control circuits. One problem of importance concerns the synchronization.

As a firsthand suggestion, based on the incomplete information available, Fig. 3 shows a possible arrangement for 12 channels, using the "Union" tube RBE12G-1. To assure continuous and correct synchronization it is suggested that a synchronization pulse is derived from the switching tube and used to start off the radial sweep on the PPI tube at the proper instant. This can be done if a small synchronization electrode is inserted in the RBE tube as shown.

The 400 cps line feeds into a frequency divider 1:4, considering that the earlier assumption of f_B = 100 cps still holds.* For simplicity a multivibrator is shown in the function of frequency divider, oscillating on 100 cps and synchronized on its fourth harmonic. The 100 cps output is filtered and the sinusoidal component applied to a single-to-three phase converter, that is utilized to deliver a six-phase voltage to the RBE tube. This voltage makes the electron beam spin around 100 times per second, delivering the time division separated channels on the terminals marked "out." At the PPI tube a saw-tooth generator is used to produce a 100 cps output. To illustrate this function a grid synchronized gas triode has been chosen. The synchronization signal kicks off the backstroke when channel No. 12 is connected so that the radial sweep starts off with sufficient accuracy from the center of the screen at the time the signal from channel 1 is in progress to develop.

It should be noted that several circuits shown in Fig. 3 are merely symbols, illustrating the various functions. When the design work commences these individual circuits shall have to be critically scrutinized, and other circuits considered which may show better performance, greater simplicity, or better suitability with respect to available components and parts.

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* See report of September 27 on the overall electronic system, page 3, where the value f_B = 100 is used as satisfactory for the presentation circuits when no particular consideration is given all the possible optical scanning and cell input circuits that may be used.

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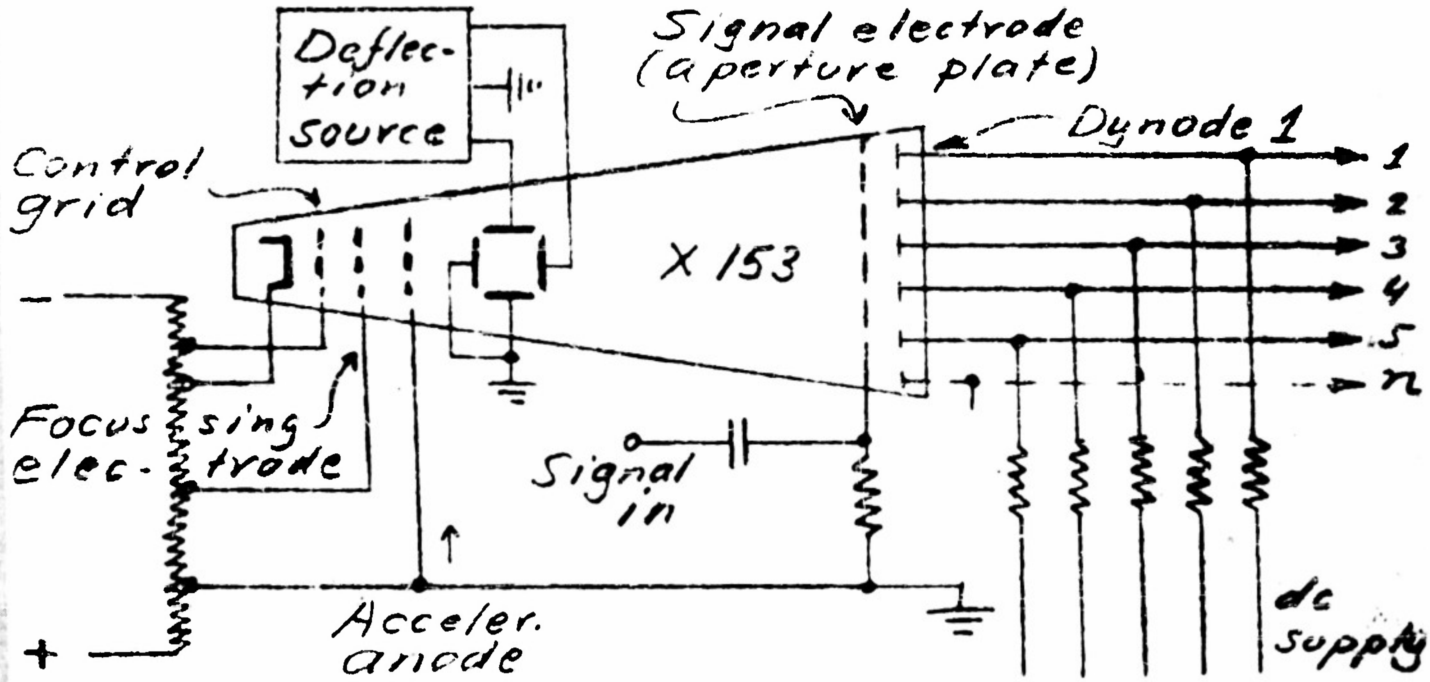
Deflec-
tion
source
Control
grid
Signal electrode
(aperture plate)
Dynode 1
X 153
1
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Fig. 1.

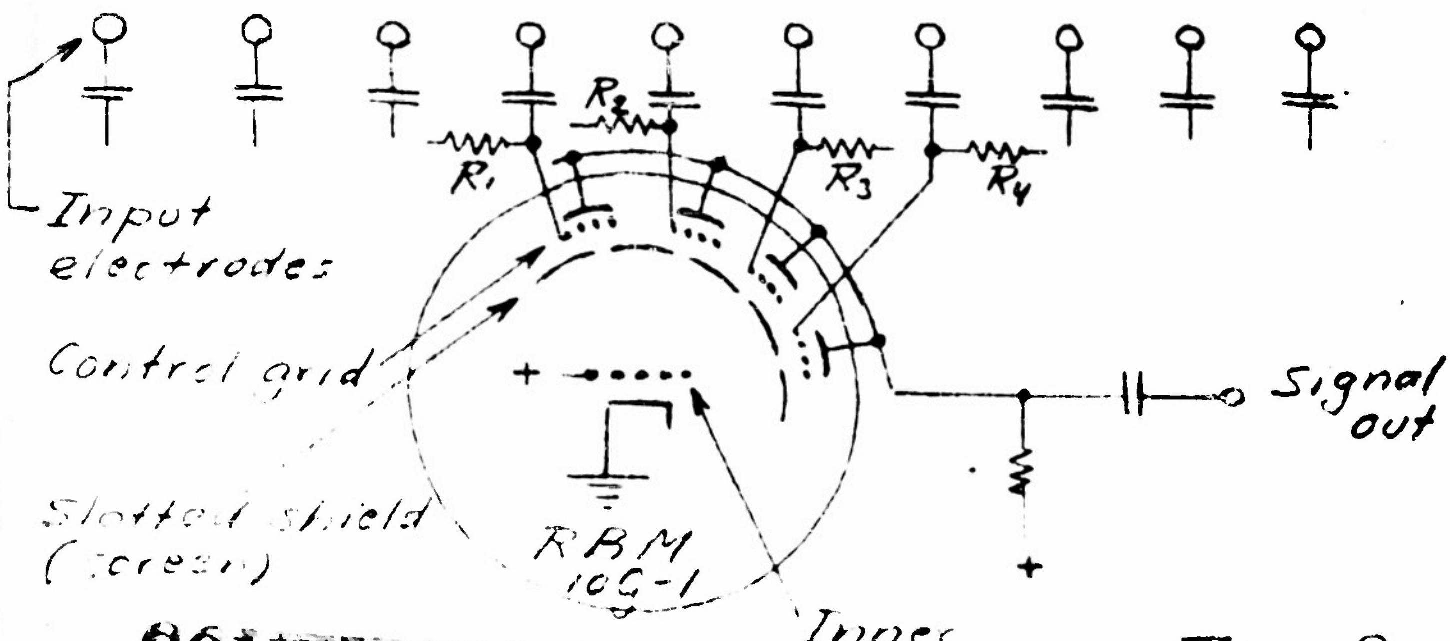
Input
electrodes
R_1
R_2
R_3
R_4
Control grid
Slotted shield
(screen)
RBM
10S-1
Inner
grid
Signal
out
+

Fig. 2.

RESEARCH DEPARTMENT

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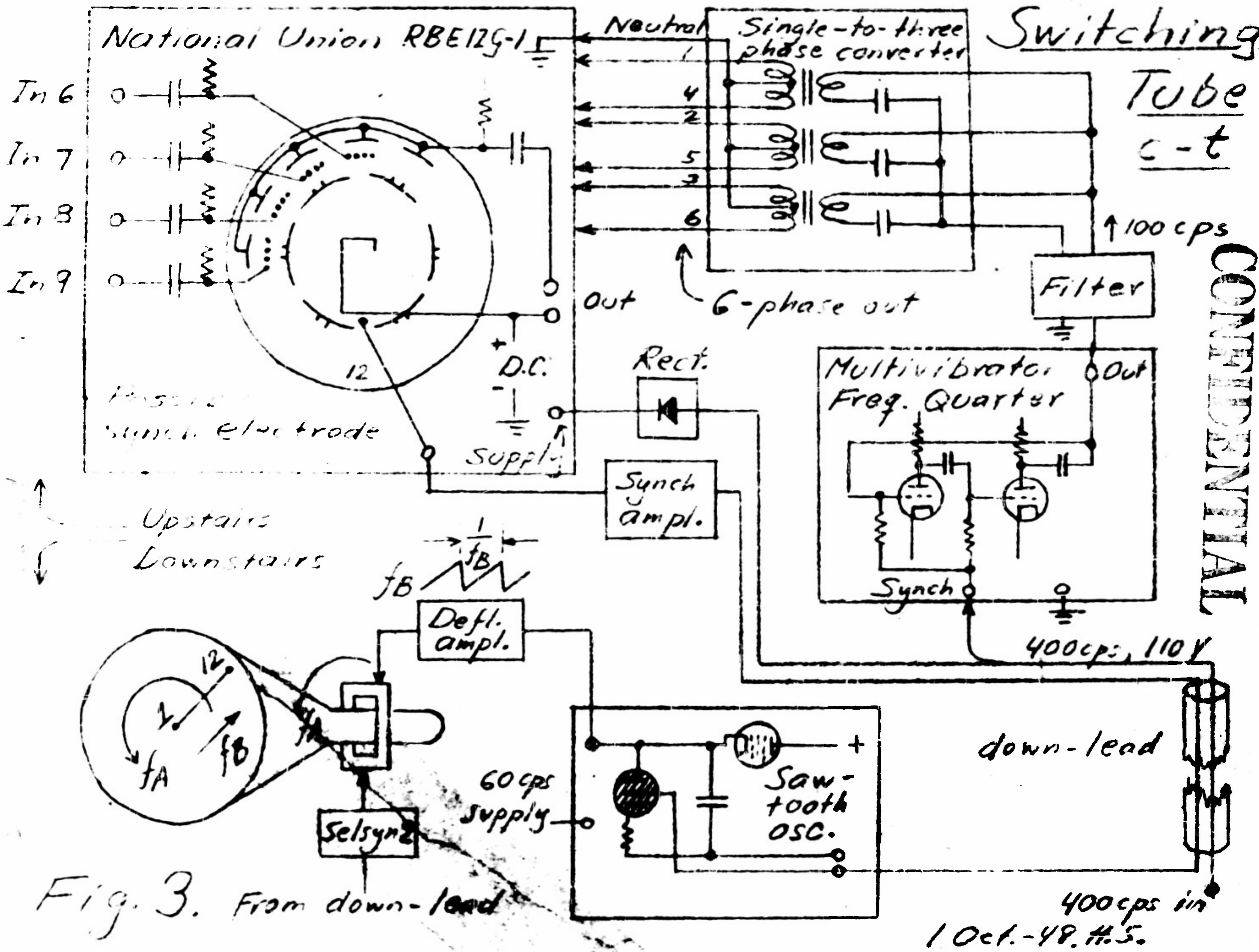

Fig. 3. From down-lead

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Magnetic Amplifiers for the
Hemispheric Search Detector, Model 1

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1. General

The following is essentially a brief orientation in the field of magnetic amplifiers, extended in case of the second harmonic type to a discussion concerning the hemispheric search detector application. Three kinds of magnetic amplifiers are discussed in the text; the control circuit type, extensively used in the power engineering field, the second harmonic type, and the airborne magnetic detector type.

While research work on magnetic amplifiers in the power engineering field has been carried out during the last forty years, or so, (see list of literature at end of report), corresponding research work on weak signal amplifiers is just commencing. An exception here is the airborne magnetic detector, on which extensive research work was carried out during the war, but the research problem of this detector is somewhat different from that of the cell amplifier in the hemispheric search detector. Accordingly it is difficult to predict at the present state of the art what the finally accepted principle of operation of the cell amplifier will be, and it is felt justified to mention all known types of magnetic amplifiers, although the second type discussed appears most promising.

Control Circuit Type of Amplifier

A magnetic amplifier includes, as an essential component, a ferromagnetic device with adjustable inductance. The conventional magnetic amplifier is supplied from an a.c. source, and the ferromagnetic device contained in this magnetic amplifier is then a saturable reactor, or transductor, or transducer. Otherwise there is no clear distinction between what is meant by a "saturable reactor" and a "magnetic amplifier," and the terms are used indiscriminately.

Initially a magnetic amplifier may be defined as an arrangement of electric and saturable magnetic circuits interlinked in such a way that a small d.c. current serves to control the reactance of an a.c. circuit, thus controlling the flow of a.c. power to the load. Only one simple circuit will be shown for the purpose of illustrating the principle, See Fig. 1. The a.c. and d.c. windings are so polarized that there is no a.c. output at the d.c. control terminals. (A more elegant solution is to use only one core with more than two legs.) When the d.c. current is changed, the magnetic properties of the cores are changed, and thus the load conditions on the a.c. input side controlled. Many variations

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of the circuit in Fig. 1 exist. Even a small change ΔI_d may cause, with proper operating point, a large change ΔI_L, so that positive power amplification, $+\Delta P_L > +\Delta P_d$ obtains. For equal impedances, then, $+\Delta I_L > +\Delta I_d$.

Of special interest is the self-saturated reactor, which utilizes feedback with or without the need for an additional feedback winding. Generally the feed back is arranged so that a rectified d.c. component is obtained from the a.c. side, which component, for positive feedbaack, aids the d.c. control current. The result of this reinforcement is that a given average saturation of the core is achieved with a smaller value of control current than would be required without feedback. If too much feedback is used instability results, and under favorable conditions, oscillations. When feedback is obtained without the need for extra windings, it may be termed self-feedback (self-exitation). When extra winding or windings are required, it may be termed external feedback (external exitation).

Magnetic amplifiers may also be provided with negative feedback to improve linearity.

An application circuit of special interest has been given by Hedstroem and Borg, Electronics, September, 1948, p. 91. It is said that this circuit is suitable for amplifying currents from photocells and thermocouples. Again, this does not mean that the noise properties of the circuit are so good that superiority over tube amplifiers obtains, particularly as the application referred to concerns vastly stronger signals than the ones encountered from the cells in the hemispheric search detector. Amplifier circuits of this type may give power amplification in excess of 10^8 times. Leaving noise out of consideration, this would indicate that a voltage of 10^{-9} volts would be amplified to become at least 10^{-5} volts, or 10 microvolts.

For fast response higher exitation frequency is needed. The inductance of the windings can then be reduced for the same impedance, which reduces the time constant of the system. In general, equivalent magnetic amplifiers operating at different frequencies can respond in the same number of cycles, thus the higher frequency unit has the faster response.

3. Balanced Second Harmonic Circuits

This solution appears particularly attractive to the hemispheric search detector application. This is evident if the solution with a conventional tube amplifier and a high secondary inductance transformer is concerned. With a cut-off frequency of, say, 1 cps, and a required secondary impedance of 1 megohm, a secondary inductance approaching 100,000 henry would be desirable. Such a value is out of the question for the small space available for the cell amplifier in the hemispheric search detector. If a more suitable coupling element was made available, the power amplification of the tube could be relied upon to yield a sufficiently low noise figure for the entire unit.

If a magnetic amplifier can be used in such a way that does not degrade the signal-to-noise ratio of the cell, it appears to offer high promise because the secondary inductance need only be high enough to yield an impedance of one megohm at, say, 5000 cps. The required value of secondary inductance is now only 10 to 20 henrys.

The principle involved in this type of magnetic amplifiers is to make use of certain hysteresis properties of ferromagnetic core material, with the useful output in the form of a second harmonic. The utilized phenomena date back to Epstein, 1902, and at least for one group of phenomena the principle may be formulated as follows: If a sinusoidal voltage is applied to the primary of a transformer containing a ferromagnetic core, of an amplitude sufficient to extend the hysteresis loop into the region of saturation, the potential appearing on the secondary winding will possess the same frequency and odd harmonics. As long as the hysteresis loop is symmetrical (with respect to the origin), this will be the case, since the symmetry precludes the production of even harmonics. If a small direct current flux is superimposed on the transformer, however, even harmonics will also appear in the output.

To remove the fundamental signal and the odd harmonics from the output, the following arrangement may be used. Two cores with primaries L_1, L_2(a.c.), secondaries L_3, L_4(a.c.), and control windings L_5, L_6 (d.c. bias) are used, the secondaries connected in series in such a way that the fundamental and odd harmonics cancel out, while the even harmonics will add. See Fig. 2.

The a.c. output can be used as a measure of the d.c. bias control voltage or current. Negative (or positive) feedback can be added as indicated symbolically by the dotted windings L_7, L_8, and better linearity obtained. The second harmonic from the pick-up windings L_7, L_8 is amplified and detected, and the d.c. fed back around the cores in such a way that the magnetic field opposes the bias field. Shields of permalloy and copper are used to prevent influence from external fields, such as the earth magnetic field. Shocks and vibrations must be eliminated.

The a.c. output may be tuned to the second harmonic up to the limit set by various stability conditions. This greatly increases the sensitivity. The sensitivity increases with a.c. input until a peak is reached, and then falls off. For greatest stability, it is best to operate at the edge of this latter region, i.e., just beyond saturation. The open-circuit sensitivity for a certain tested magnetic amplifier was 43 millivolts root-mean-square secondary output per microampere input.

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A cause of fluctuations is the discontinuities in magnetization (Barkhausen effect). Such fluctuations may be below 0.01 microampere in the magnetic amplifier referred to above. Another fluctuation, known as the "background" is caused by the fact that a weak second harmonic appears in the output even when there is no input. If cancelled, this second harmonic sets a variable zero level, which may be considered as a noise source, although the period of fluctuation may be very long. It should be possible to introduce proper automatic zero restoration circuits.

Information on noise level indicates that input currents as small as 8 microamperes has been used in practice and 0.04 microamperes has been detected, or 10 microvolts (input impedance 250 ohms). This means that the input power is of the order of 10^{-13} watts, while the signal power available to operate the search detector may be of the order of 10^{-19} watts, roughly, thus the difference being 10^{6} in power, or 10^{3} in voltage. This is not too discouraging.

This method may be referred to as the "second harmonic balance" principle.

4. The Magnetic Airborne Detector

The principle of the airborne "magnetometer" is as follows: Two thin cores of highly permeable alloys are arranged parallel to each other. See Fig. 3. The cores are saturated simultaneously and the voltages across the two primaries are always equal. The cores have opposite polarity. If the cores are placed parallel with the field lines in a fixed magnetic field, one core will saturate a little bit earlier, the other a little bit later. Thus, through a short moment, the coils will not have equal impedances and will not have equal voltages. A secondary coil is arranged so that normally there is no change in the enclosed field and no emf is induced. During the short moment of inequality in impedance and magnetization, a pulse will be produced in the secondary, which is rectified in a special circuit and yields a d.c. output. For small external fields the amplitude of this pulse is proportional to the field strength. Saturation is produced even by very weak fields. A separate d.c.-fed coil is arranged so as to buck out the earth's magnetic field, so that the magnetometer will measure only the small unbalanced field. The bucking current is supplied automatically.

It appears that the simplest connection of this amplifier to a cell would be to directly turn the radiation signal into a magnetic field, and expose the magnetometer to this field as if it were an earth magnetic field variation. No compensation is then needed or desirable, as the signal field appears and vanishes from a zero-level set by Johnson noise in the combination of the cell impedance and the magnetometer input circuit impedance. As the impedance level may be very low, a few ohms, the Johnson noise level is very low. A tentative circuit is suggested in Fig. 4.

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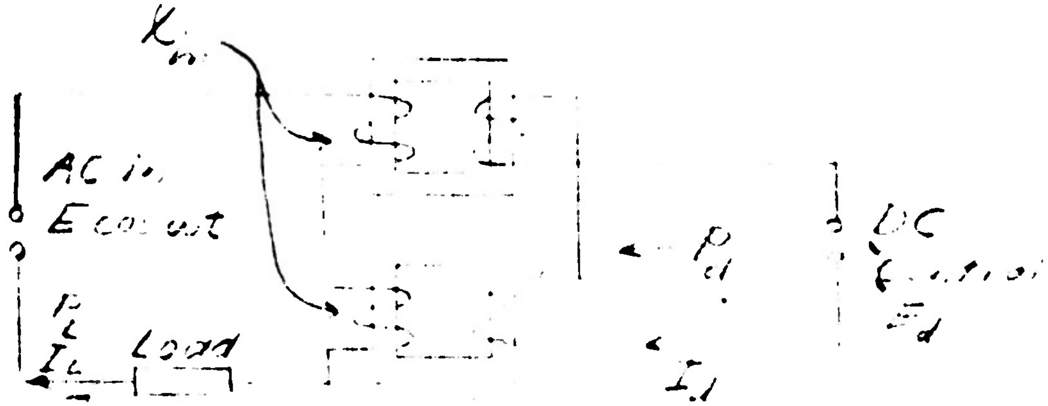

Power P_L is controlled

Fig. 1.

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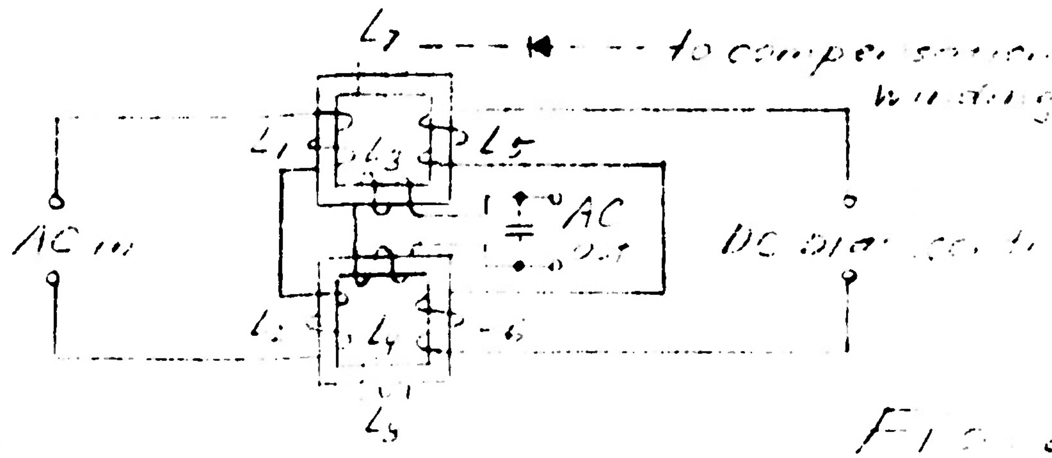
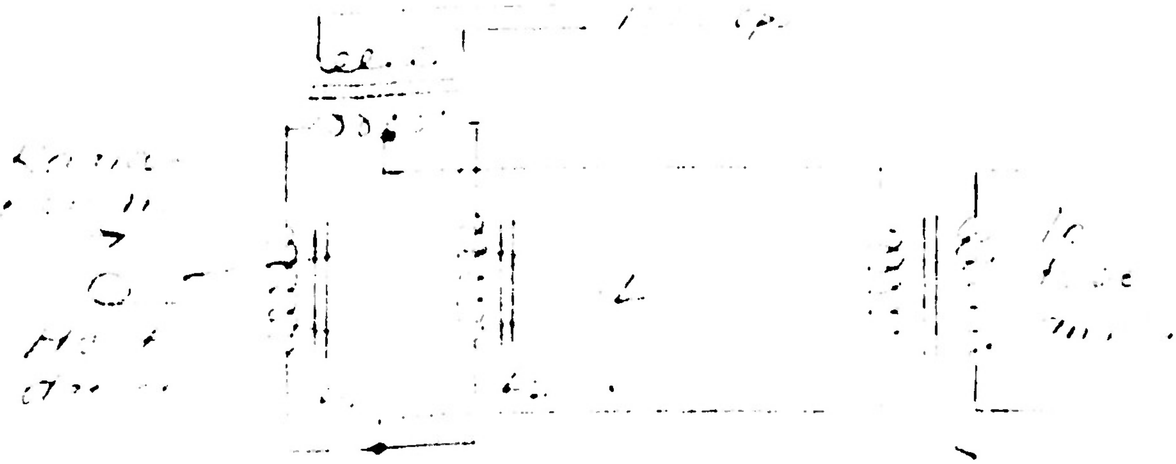


Fig. 2

Fig. 3



Enclosure 5

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Report on a Discussion with Dr. G. B. B. M. Sutherland

R. Clark Jones

October 13, 1948

Dr. G. B. B. M. Sutherland, who is one of the outstanding English authorities in the infrared field, visited the Polaroid Corporation on Wednesday, October 6.

On the basis of the authorization granted in a letter dated October 4 from Captain John G. Johns, Commanding Officer, Boston Branch, Office of Naval Research, the hemisphere search detector study contract was discussed with Dr. Sutherland in detail for about two hours in the morning of October 6. During this discussion considerable attention was paid to the problem of obtaining a strip of lead sulfide cells of the configuration required for the 18-element scanner.

Dr. Sutherland thought that it was quite feasible to construct in a single evacuated envelope the array of 18 photoconductive strips shown in the middle figure on page 4 of the report dated August 18, 1948, by Grey and Jones. Dr. Sutherland furthermore thought that the composit detector could be made either by the chemical or by the evaporation process. A specific design was worked out which will fit in the available space, and which will permit the elements to be cooled to liquid air temperature.

Dr. Sutherland felt confident that the composit detector could be manufactured by the British Thompson-Houston Company at Rugby, England.

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